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By G. Lehr.

From "L'Aeronautique," July, 1924.

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AVIATION ENGINES IN THE ENDURANCE CONTEST.\*

By G. Lehr.

The contest for engines of great endurance, which are now being tested at Chailais-Meudon, had entries of 13 types by the following firms: Breguet, 2 types; Farman, 1 type; Fiat, 1 type; Hispano-Suiza, 2 types; Lorraine-Dietrich, 2 types; Hispano-Suiza, 2 types; Lorraine-Dietrich, 2 types; Panhard-Levassor, 1 type; Peugeot, 1 type; Renault, 2 types; Salmson, 1 type.

Some time before the date set for the delivery of the engines, the Fiat withdrew and was followed, at the time of closing the entries, by the Hispano-Suiza (both types), the Lorraine-Dietrich (one type) and the Peugeot, thus leaving only eight engines in the contest.

It is known that the rules left the greatest latitude to the contestants, as well regarding the general design of the engines and their revolution speeds, as regarding the cooling system and the kind of fuel. The only restrictions concerned the power, which had to be between 350 and 450 HP, and the weight per HP, which could not exceed a certain quite large limit. Fuel and oil for five hours' flight had to be included in calculating this weight, so that an engine of higher economic efficiency could

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\* From "L'Aeronautique," July, 1924.

weigh more than one of lower efficiency. The explosion cycle was not stipulated, the sole obligation being for the engine to be an internal combustion engine. Lastly, the propeller speed was limited to a certain maximum, compatible with its mechanical strength. The maximum R.P.M. of the propeller was defined by the expression  $32000/\sqrt{P}$ ,  $P$  designating the normal HP of the engine.

Notwithstanding the liberty granted the constructors, the engines entered in the contest all came within the limits prescribed by experience with aircraft and automobiles. For example, no attempt was made to substitute, for the system of power transmission by connecting rod and crank, any of the new systems of power transmission by means of cams and rollers or gear wheels, advocated by certain inventors. Neither did any two-stroke cycle engines appear.

No one ventured to attack the problem of employing heavy fuel, in spite of its great importance for the safety of aerial navigation, an importance recognized by the managers of the contest in the form of a large bonus to any engine using fuel with ignition temperature above  $35^{\circ}\text{C}$  ( $95^{\circ}\text{F}$ ). Contrary to those who think of progress only in a revolutionary form, we believe that the contestants were wise in basing their efforts on the important progress already made and in seeking further improvements rather than entirely new methods.

It would naturally be premature to try to draw lessons from this contest which has hardly begun, but it may be of interest to review and compare the principal methods adopted.

From the viewpoint of the general arrangement of the cylinders, the engines differ as follows:

1. Six engines with V arrangement of cylinders, three of which actually appeared (Panhard, Renault Nos. 1 and 2), the other three (H.-S. No. 2, Peugeot, Fiat) having been withdrawn;
2. Four engines with W arrangement of cylinders, two of which were presented (Farman, Lorraine-Dietrich No. 1), the other two (L.-D. No. 2, H.-S. No. 1) having been withdrawn.
3. Two engines with two rows of vertical cylinders, two Breguet, both actually presented;
4. One radial engine, one Salmson in double star.

With respect to cylinder capacity, they may be classified as follows:

Engine	Cylinder capacity		Number of cylinders	Bore		Stroke	
	liters	cu.in		mm	in.	mm	in.
Peugeot (withdrawn)	42.2	2575.18	12	160	6.30	175	6.89
Salmson	37.6	2294.47	18	125	4.92	170	6.69
Lorraine-Dietrich No.2 (withdrawn)	36.6	2233.45	18	120	4.72	180	7.09
Panhard	31.5	1922.23	12	140	5.51	170	6.69
Renault No. 1	30.5	1861.21	12	134	5.28	180	7.09
Hispano-Suiza Nos.1 and 2 (withdrawn)	27.7	1690.34	12	140	5.51	150	5.91
Farman	25.4	1549.99	12	130	5.12	160	6.30
Lorraine-Dietrich No. 1	24.4	1488.97	12	120	4.72	180	7.09
Renault No. 2	23.7	1446.25	12	134	5.28	140	5.51
Breguet Nos. 1 & 2	23.0	1403.53	16	106	4.17	163	6.42
Fiat (withdrawn)	16.2	988.58	12	115	4.53	130	5.12

The above table shows that, of the engines enrolled for the contest, nine had 12 cylinders each, including the five engines which were actually presented. The 12 cylinder engines are therefore in the majority.

This is doubtless due to the fact that there can be obtained with this number the complete balancing of the forces of inertia of the first and second order and a sufficiently uniform torque (deviation of about 1.45% from the mean). The balance attained suffices to avoid appreciable vibrations and the uniformity of the torque allows the easy adaptation of reduction gearing.

As regards the bore, they have retained the mean dimensions which have stood the test. In the engines remaining in the contest, the largest bore does not exceed 140 mm (5.51 in.) and the smallest is 106 mm (4.17 in.), which is one of the smallest now used in aviation engines. The length of stroke is less important in itself. More important is the mean velocity of the piston resulting from the rotation speed adopted for the engine shaft. In this connection, it is not possible to give exact figures, since the revolution speeds have not yet been definitely determined. The following figures, however, may be considered approximate:

			m/s	ft./sec.
Breguet (Nos. 1 and 2), mean piston speed			13.5	44.3
Lorraine-Dietrich	"	"	10.0	32.8
Renault (Nos. 1 and 2)	"	"	9.5	31.2
Farman	"	"	9.0	29.5
Panhard	"	"	8.5	27.9
Salmson	"	"	8.5	27.9

Excepting the Breguet engines, whose moving parts were specially designed for extreme lightness, the types presented function at piston speeds below the figure actually sanctioned by experience, which is about 10 m (32.8 ft.) per second. This was demonstrated in an endurance test where it was necessary to lower the thermal and mechanical fatigue of the principal parts.

We will terminate this list of the general characteristics by indicating the method of drive adopted for the propeller. The speed limit stipulated for the latter easily enabled direct drive with the usual engine speeds. A small bonus was allotted to engines with reduced propeller speed, in order to allow for the resulting increase in the efficiency of the engine-propeller group. The formula for calculating this bonus was very logically worked out and took into account not only the gain in effective horsepower, but also the saving in fuel. The direct drive was adopted, however, by the majority of the contestants. Five of the thirteen engines had reduction gears (two Breguet, the Farman, Fiat and one Renault). As a result of the withdrawal of four engines with direct drive and only one with reduction gear, there is now the same number of engines of each type. Three of the engines with reduction gear were specially designed, however, for the contest and do not have the benefit of previous experimentation, which probably diminishes their chances, since only one of the direct-drive engines was specially designed. This fact must not be forgotten in drawing conclusions from the result of the contest.

Without entering into a detailed study of the construction of the engines presented, some of which are already well known, it may be of interest to compare certain details.

Cylinders.-- Most of the cylinders adopted by the contestants have water-jackets of autogenously welded sheet-steel. Only one constructor, Mr. Breguet, employed water-jackets (Fig. 1) of aluminum alloy, notwithstanding its excellent thermal properties. It may be remarked that the latter type, which is being increasingly used, especially in the United States, had been adopted by four of the engines which were withdrawn from the contest. It is regrettable that this fact will render it impossible to make a fair comparison between the two types.

Pistons.-- All the pistons are aluminum, except those in the Breguet, which are made of an alloy of aluminum and magnesium.

The latter pistons have, moreover, a very peculiar shape and are made in two parts with a fitted head. The union with the connecting rod is of a special type. The small end of the connecting rod carries two machined gudgeons, forming an integral part of the connecting rod and serving as the piston pin. For assembling the connecting rod and piston, the latter has only semi-bearings and the union is made by means of two caps secured by bolts and nuts.

Connecting rods.-- These differ according to the arrangement of the cylinders. Following the order of increasing complexity, we

first encounter the Breguet connecting rods, which are the simplest, since the engine has two rows of cylinders, each row driving one crankshaft. There is, therefore, only one connecting rod for each crank pin. The connecting rod is tubular and the simplicity of its construction and of the calculation of the stresses rendered it possible to attempt a bold solution, namely, the employment of duralumin. The large end of the connecting rod is lined, the anti-friction bushing being welded directly to the duralumin by a special process. This method of construction, as also that employed for the pistons, makes it possible to lighten the moving parts and considerably reduce the forces of inertia. For equal fatigue, we can therefore adopt a higher piston speed and obtain more power from a given cylinder capacity. The employment of high speeds necessitate a special study of the distribution, which, as we shall see farther on, has already been made.

Among the V engines, the Renault has its usual system of connecting rods, consisting of a master connecting rod carrying a pin about which the auxiliary connecting rods oscillate. This system, though the simplest to make, has the disadvantage of disturbing the law of motion of the piston connected with the auxiliary connecting rod, which causes either an angular shifting of the top dead center or a lack of uniformity of the stroke and, in every case, a modification of the secondary forces of inertia. In order to reduce the latter, the ratio of the length of the connecting rod to the stroke was increased in the engines presented, both of



which have the same bore. One of them differs from the military type previously built by the same company, only in improvements in details. This elongation of the connecting rod has, moreover, the advantage of reducing the lateral pressure of the pistons on the cylinders.

The other V engine, the Panhard, has a forked connecting rod which enables accurate rotation around the crank pin. This is more difficult to make than the preceding one and the wear of the connecting rod bearings in the endurance tests sometimes leaves something to be desired. In order to eliminate the effect of differences in expansion, the bushing carried by the forked connecting rod, which assures the turning on the shaft, was not made of bronze but of lined steel. The connecting rod turns exteriorly on the middle portion of this bushing. In Fig. 2, BB is a section of the connecting rod. The bushing is cooled by a copious flow of oil, produced not by oil grooves, which have the disadvantage of reducing the friction surface, but by interior perforations. A median orifice GG receives the oil which leaves the crank pin under pressure. The oil then passes through channels following the generatrices of the bushing. The oil, after passing through the bushing, flows back to the bottom of the crankcase, through perforations OO in the large end of the connecting rod. The lubrication of the cylinder depends on the play left in A. A sufficient cooling circulation can thus be obtained, without lubricating the cylinders to excess.

It is extremely difficult to make a similar device enabling the accurate revolution of three connecting rods around the same crank pin. The assembling, difficult in the case of two connecting rods, becomes almost impossible for three, with the desired precision. A system, consisting of a master connecting rod and two auxiliary connecting rods was adopted.

The Lorraine (Fig. 3) and the Farman have very similar connecting rod systems, consisting of a master connecting rod of H cross-section and two tubular auxiliary connecting rods. The piston pins are attached to the small ends of the connecting rods with the aid of bolts. This system presents, from the kinetic viewpoint, the disadvantages already mentioned in connection with the Renault system.

Lastly, the Salmson has the connecting rod system well known in engines of this make, namely, an H master connecting rod with eight pins on its large end, about which the tubular auxiliary connecting rods oscillate.

Shafts.-- The types differ greatly, not only in the number of cranks, according to the number and arrangement of the cylinders, but also in the ratio between the number of piston pins and crank pins, in the kind of bearings (plain or ball) and in their structure (in one piece or several).

The shafts of the Renault engines have six cranks with plain bearings including one bearing between each crank and the next. The middle bearing, which suffered great fatigue in preceding en-

gines, was lengthened. The shaft of the Panhard is similar.

The shafts of the Lorraine and Farman have only four cranks and three plain bearings, two cranks being inserted between each two successive bearings. The shafts are all made in one piece.

The Salmson shaft is very simple. It has only one crank and two ball bearings. Both master connecting rods are mounted on a single smooth bushing surrounding the crank pin. The shaft is in two pieces. It is provided with balancing masses, indispensable with the radial arrangement of the cylinders. It is well to remember, in this connection, that a radial engine would enable the perfect balancing of the alternate forces of inertia by means of suitable counterpoises, if the adopted mechanism accomplished the accurate revolution of the connecting rods around the crank pin, which is not the case in the Salmson.

The Breguet engines each have two shafts with ball bearings. There are two cranks between each two successive bearings. Each shaft is in four parts, so as to enable the assembling of the bearings. The parts of the crank shaft are assembled by means of tapered bolts secured by nuts and lock-nuts.

Reduction gears.— Two types are employed. Farman's is a planetary gear, (Fig. 4). Its operation is explained by the accompanying diagram. The engine shaft M drives the toothed wheel C which engages the planetary S. The latter engage the toothed wheel F attached to the crankcase. The propeller shaft H is

forged in one piece with the pivots of the planetary and is rotated in the same direction as the engine shaft, but at only half the speed.

The reduction gears of the Renault and Breguet engines are of the spur type. In the Breguet engines each crank shaft carries a small gear-wheel which engages with a large gear-wheel on the propeller shaft. It is the system used in the Bugatti engine constructed at the close of the war, but, in order to reduce the fatigue of the gears, there has been interposed between each crankshaft and its gear-wheel a flexible centrifugal coupling, (Fig. 5). The latter has two concentric crown-wheels. The outer wheel, borne by the shaft, encloses a certain number of cylindrical bearings, whose axes are oriented radially. In each of them there moves a piston forming a weight, connected by a rod with the inner gear-wheel. These weights, subjected on the one hand to centrifugal force and, on the other hand, to the centripetal force of the rod, assume a certain position of equilibrium. The slight variations in torque simply vary this position and are not transmitted to the gear-wheel.

Valve gear.— This has been carefully studied. Constructors know that this is often the weak point which, in an endurance test, is often the first to break down.

The valve springs, in particular, suffer repeated shocks which may result in their breaking. One of the most difficult problems to solve is that of the exhaust valves, which are like-

wise subjected to shocks, with the aggravating circumstance of a high temperature. The fatigue suffered by the valve gear seems to be the only serious obstacle to the employment of high engine speeds. The valves of automobile engines have functioned perfectly for many hours at speeds of 5000 to 6000 R.P.M., but these speeds are far below those employed in aviation. These results are largely due to the employment of triple springs. Most of the engines in the contest have double springs.

On the Breguet engines, the question of the durability of the springs has been solved by their elimination, the valves being operated by compressed air. A small compressor, controlled by the camshaft, forces the compressed air under pistons attached to the valve-stems. To be accurate, there are springs, but they are employed only in starting and can be relatively very weak. In these engines, designed for running at high speed, the exhaust valves are cooled by oil.

In the Renault engines, the improvements made in the valve gear have to do with the tightness of the camshaft housing, with increasing the cross-sections of the gas passages and with the ease of dismantling. The former arrangement for the passage of the valve-rockers consisted of ports in the camshaft housing. It was difficult to make these ports tight. In the present model, the rocker is entirely free and it is only necessary to assure the tightness of the cylindrical ports along a cross section, instead of assuring it parallel to the generatrices. This arrangement

presents a certain analogy with the valve gear of the Lorraine engine.

In order to increase the cross-sections of the gas passages, the valves were inclined, which rendered it possible not only to adopt a greater diameter for the inlet valves, but also to leave a greater interval between them and thus to improve their cooling.

Lastly, the valve gear was made in a way to simplify the necessary adjustment after dismantling the cylinders. The intake manifold is no longer attached to the cylinders, but to three supports resting directly on the crankcase. The valve gear has a slip joint, in order to facilitate assembling.

The valve gear of the Farman engine consists of camshafts located in the crankcase. This arrangement renders it possible to employ two camshafts, one of them serving to operate the valves of two banks of cylinders at the same time.

The Salmson, like all radial engines, has a valve gear with a rotary cam in the crankcase. Since the star is double, there are two cams, both in front of the engine. The valves of the rear star are operated by long valve-rockers.

Of all the different valve-gears, the most original is the Panhard with sleeve valves (Fig. 6). Hitherto it has not been employed in aviation on account of its weight. The constructor considered it suitable for engines whose essential characteristic is durability, though obtained, to a certain degree, at the expense of lightness.

The chief advantage of such a valve gear is the elimination of fragile and multiple parts, such as valves, springs, valve-rockers and rollers. Experience will determine whether the disadvantages of the sleeve valve are less serious than the combined disadvantages of all the above parts. This device is being increasingly adopted in automobile construction. This favor is evidently due in part to the lessening of the noise which it renders possible, a consideration at present non-existent in aviation, but it is also attributable to other causes. The Panhard cylinder is characterized by the easy accessibility of the spark plugs, for which the cylinder head can be used. The height of the engine can be considerably reduced.

The structure of these cylinders is shown in the accompanying figure. The cylinder head is fitted inside in such manner that the effect of the pressure is to apply it more closely to its seat. The two sleeves, whose sliding opens the intake and exhaust ports at the proper time, are operated by connecting rods driven by a shaft with eccentrics. These sleeves are steel and are lined. The employment of steel has made it possible to reduce their weight. The difficult point in the system is the lubrication and the determination of the clearances to give the rubbing surfaces. The Panhard Company was especially qualified to solve this problem, because of their long experience with such matters.

Lubrication.-- With the exception of the Farman, whose crank-

case serves as an oil tank, all the engines function with a dry crankcase, which renders it possible to keep the temperature of the oil sufficiently low. Among the special lubrication devices, we can cite the use of the centrifugal purifier in the oil circulation of Renault engines. Experiments on the wear of lubricated rubbing surfaces with oils of various degrees of purity have shown the considerable effect of solid particles in the oil used. The maximum wear was observed with oils taken from engines functioning with fuel of low volatility, but the oils from gasoline engines also contain appreciable quantities of carbon and metal particles. We can therefore hope, by continuous purifying, to reduce considerably the usual wear of the bearings.

In the Panhard engine, another kind of improvement has been made in the lubrication. In order to provide, under all circumstances, sufficient lubrication for the cylinders and the large ends of the connecting rods, there is, alongside the usual lubrication circuit, a second circuit supplied by a distributor and a special pump. A circular oil groove, on one of the webs of each crank, receives a jet of oil from the pump. By means of the distributor there is delivered periodically a constant supply of oil to all the oil grooves, thus assuring uniform lubrication of the various organs.

Cooling.— All the engines actually participating in and even those only enrolled for the contest are water-cooled. It does not follow, however, that cooling by air has been definitely condemned.



On the contrary, the American Army Air Service, encouraged by the results obtained with the 200 HP Wright-Lawrence J-1 engine, has decided to employ henceforth, under 300 HP, only air-cooled engines.

The power limitation perhaps explains the absence of air-cooled engines from the contest. It must not be forgotten that all the engines were presented at a reduced power, in order to pass the required endurance test and could easily furnish 50 to 100 HP more, if more moderate test conditions were imposed. It would, therefore, have been necessary to design a 400-500 HP air-cooled engine, a type which it has not yet been possible to construct in any country.

The water circulation systems adopted present no particular originality. In the Panhard, the water enters and leaves through pipes in the tops of the cylinders. The passage cross-sections are so dimensioned that a third of the water circulates in the cylinder-head, a third traverses the water jacket of the cylinder and a third passes directly to the next cylinder.

Ignition and carburetion.— All the engines have double ignition, the spark being furnished by magnetos in the Renault, Lorraine and Salmson. The Breguet engines employ continuous-current generators. The Farman employs a combination of the two methods, magneto and generator. The carbureters present no peculiarity. It may be remarked that questions of flexibility, of smoothness in picking up and of good functioning at low tempera-

tures are not considered in making the awards. The only important thing is the fuel consumption at the test speed, so that the carbureter plays a secondary role in this test. The greater or less saving in fuel does not, in fact, depend entirely on the carbureter, as is commonly believed. The richness of the fuel mixture employed in the endurance test is nearly always determined by the necessity of assuring a good condition of certain fragile parts, such as the pistons and exhaust valves. The carbureters would enable more economical mixtures, but the engine would not stand them.

What lessons can be learned from the contest? In the first place, it will certainly show us some good engines. It will also give us useful data on the stresses which can be imposed on the principal parts, in order to obtain greater endurance than has hitherto been possible. The most important lessons will, perhaps, proceed from the more or less serious accidents which may occur during the tests. The careful investigation of accidents, the search for their causes and the means of avoiding their recurrence will certainly result in important progress in future engine construction.

Note.— On July 1st, the situation of the engines admitted to the contest was as follows:

The Farman engine, after completing its preliminary bench and flight tests, had begun its endurance test.

The Breguet engines had not completed their preliminary bench

tests.

The other engines had passed their preliminary bench tests and were being installed for the flight tests.

Translation by Dwight M. Miner,  
National Advisory Committee  
for Aeronautics.

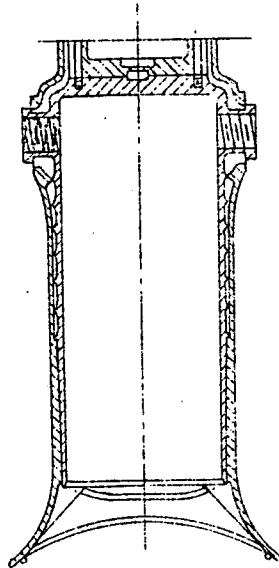


Fig. 1 Cross-section of cylinder  
of Breguet engine.

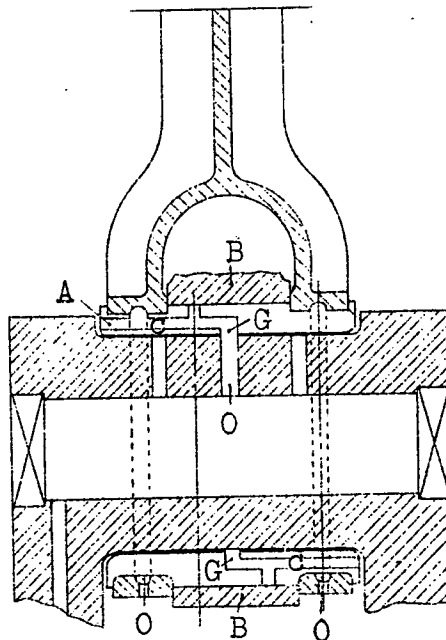


Fig. 2 Section of forked connecting-  
rod of Panhard engine.

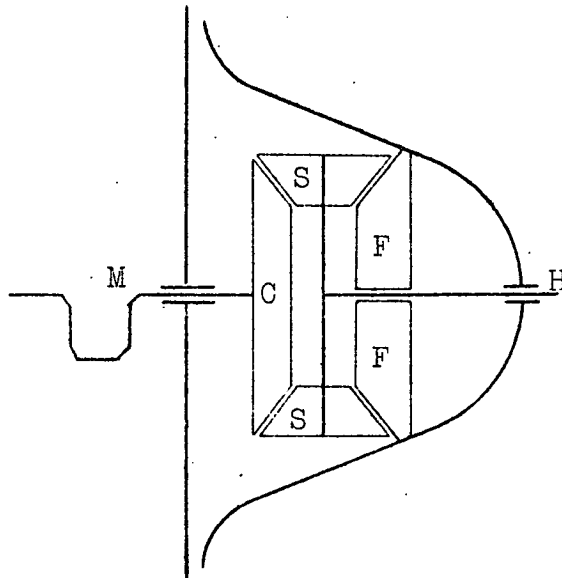


Fig. 4 Diagram of reduction gear of Farman engine

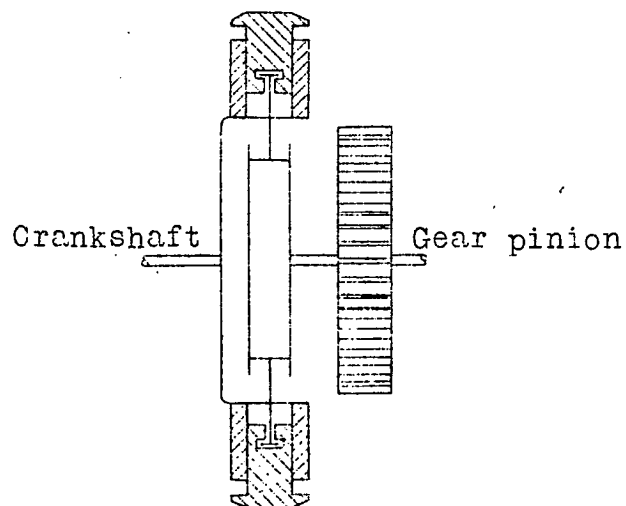


Fig. 5 Diagram of flexible centrifugal coupling of Breguet engine.

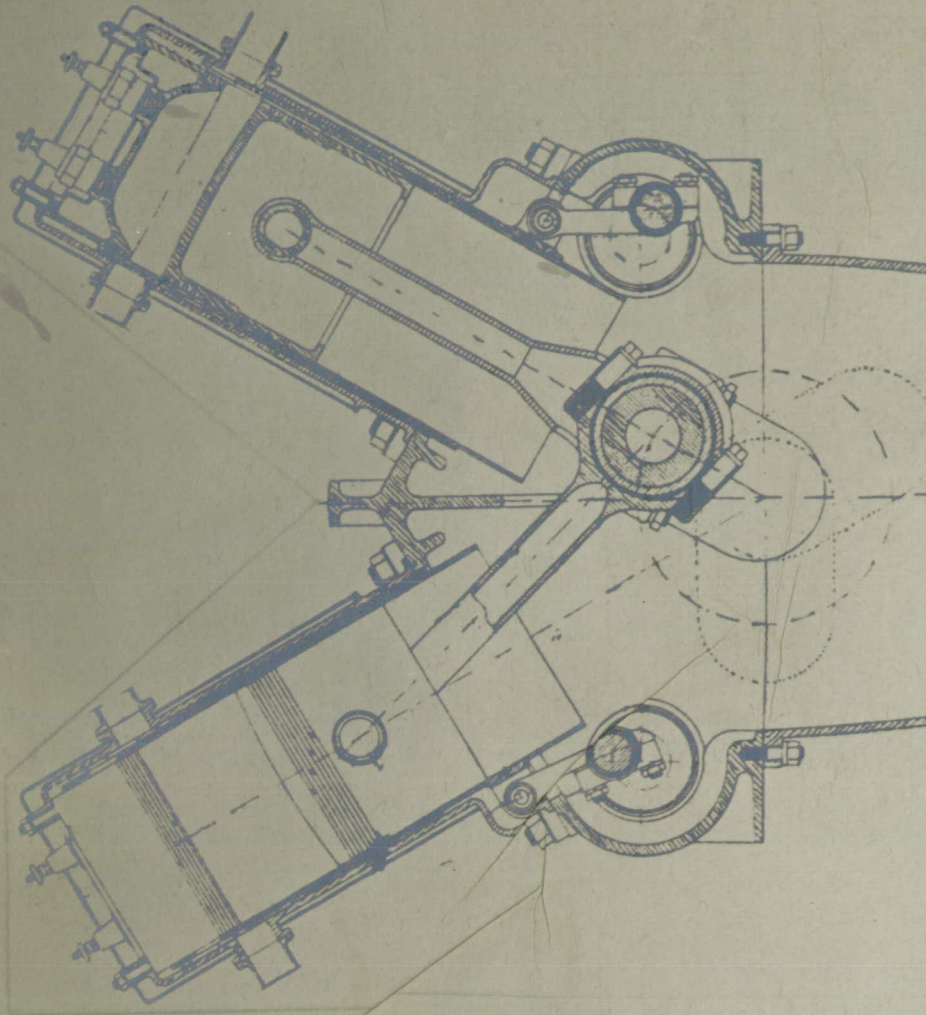


Fig. 6 Cross-section of Panhard-Levassor engine with sleeve-valve

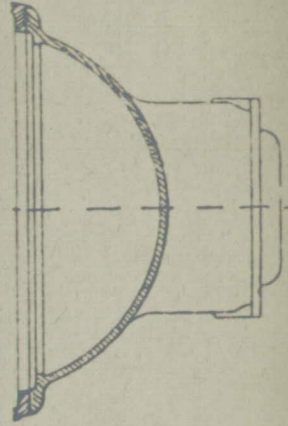


Fig. 3 Connecting-rods of Lorraine engine.